Tempe Fire Department Policies and Procedures
Hydraulics
403.03
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DEFINITIONS

Hydraulics - The mechanics of fluid at rest and in motion.

Fire Service Hydraulics - The study and understanding of water at rest and while flowing through fire protection equipment, as relating to actual fire department operations. Also, the study and understanding of the fire extinguishing properties of water.

SCIENTIFIC LAWS RELATING TO WATER

Law of Heat Flow - This law specifies that heat tends to flow from a hot substance to a cold substance. It also establishes the ability of one substance to absorb heat from another substance. This law qualifies water to be used as an extinguishing agent through its heat absorbing properties. The heat flows from the hot (fire), to the cold (water), and extinguishment is accomplished.

Law of Specific Heat - This law is a measure of the heat absorbing capacity of a substance. It states that one pound of water will require (or absorb) one British Thermal Unit in raising its temperature 1° Fahrenheit.

Law of Latent Heat of Vaporization - This law is a measure of the quantity of heat absorbed by a substance when it changes from a liquid form to a vapor form. It states that water will require 970 BTUs per pound of water to completely (100% conversion) turn it from a liquid form (212°F) to a vapor form. The water in the city mains is typically 65°-80°F. Therefore, the difference between 212°F and the water main temperature is that much more heat absorbing capability.

Law of Conversion Expansion - This law specifies that when a substance is converted from a liquid form to a vapor form, that a volumetric expansion will be realized. This rate of expansion will be consistent with each particular substance. Water, when converted from liquid form to vapor form, will expand approximately 1700 times its volume. This expansion is practically instantaneous, upon conversion. The 1700X expansion rate is based on a temperature rise from 212°F to 213°F. If the water is introduced into an atmosphere that is superheated (above 1000°F), the resulting expansion can be as much as 2500 times.

Principle of Fire Extinguishment by Cooling - To extinguish any fire by cooling, the cooling media must absorb heat at a faster rate than the heat is being produced by the fire. The cooling media must reduce the temperature below the ignition temperature of the involved fuel before extinguishment is possible. Fire streams must cool the involved fuel below its ignition temperature to accomplish extinguishment by cooling. Effective extinguishing action is dependent upon instantaneous transfer of heat from the involved and exposed materials to the water that is being applied, and the volume of heat transfer must be sufficient to bring the involved fuel to below its ignition temperature.

FIRE STREAMS

A fire stream is a stream of water from a fire appliance after it leaves the nozzle and until it reaches its desired point.

The main characteristic of a good fire stream is that it meets the requirement of the particular fire upon which it is being used under the existing conditions.

Types of Fire Streams

Solid Stream - A compact stream of water with a minimum number of detaching particles.

Broken Stream - A stream of water that produces large coarse divided droplets of water that have greater penetrating capability than a fog stream.

Fog Stream - A stream of water that produces small finely divided droplets of water that absorb heat better than a solid stream.

Sizes and Volumes of Fire Streams

Small Stream - A low volume stream discharging less than 40 gallons per minute, including those fed by booster lines.

Hand Stream - A medium volume stream discharging from 40 GPM to 350 GPM.

Master Stream - A large volume stream discharging more than 350 GPM.

AREA OF COMMON SHAPES

Square: Surface area = side X side.

Rectangle: Surface area = length X width.

Triangle: Surface area = $\frac{\text{base X height}}{2}$.

Circle: Surface area = .7854 X diameter^2 or 3.1416 X radius^2.
Circumference = 3.1416 X diameter.
Diameter = $\frac{\text{circumference}}{3.1416}$.

VOLUMES OF COMMON SHAPES

Cube: Volume = side^3.

Rectangular Solid: Volume = length X width X height.

CHARACTERISTICS OF WATER

For all practical purposes, water is considered to be non-compressible, and its weight varies at different temperatures.

1 cubic foot of water = 62.5 pounds
1 cubic foot of water - 7.5 gallons
1 gallon of water = 8.35 pounds

PUMP DISCHARGE PRESSURE

Net pump discharge pressure (PDP) takes into account all factors that contribute to the amount of work the pump must do to produce a fire stream.

PDP = FL + NP + AP ± EL

Where:

PDP = Pump discharge pressure.
FL = Friction loss.
NP = Nozzle pressure.
AP = Appliance loss.
EL = Elevation change.

Discharge from circular openings can be calculated using the following formulas:

GPM = 29.7 X D^2 X √ P

Where:

GPM = Discharge in gallons per minute.
D = Diameter of the opening in inches.
P = Flow pressure in pounds per square inch (psi).
29.7 = Constant

The above formula assumes that the opening has a discharge factor of 1.0, such as a smooth bore nozzle. For other openings, another factor must be used:

Open Butt = .90
Hydrant Butt = .90
Sprinkler Head = .80

FIREGROUND NOZZLE PRESSURES

Smooth bore nozzle pressures are as follows:

Smooth bore hand lines = 50 psi.
Smooth bore master streams = 80 psi.

Fog nozzles, regardless of size, are designed to be operated at the standard nozzle pressure of 100 psi.

FRICTION LOSS (FL)

The three major components of friction loss are size of hose, GPM flow, and the length of hose. The smaller the hose the greater the friction loss. The greater the gallons per minute (GPM) flow, the greater the friction loss. The longer the hose, the greater the friction loss.

<u>Handline Formula for Friction Loss</u>

[(gpm X n) ÷ 10] - 10 = FL per 100 feet of hose.

n = conversion factor.

n = 5 for 1½" > 100 gpm
n = 4 for 1½" < 100 gpm
n = 2 for 2"
n = 1 for 2½"

IMPORTANT: Due to the construction of Taskmaster 1 ¾" hose, a conversion factor will not be used for calculating Tempe Fire Department 1 ¾" hose lines. See the guideline on page 8 for all calculations of engine pressure.

<u>Supply Line Formula for Friction Loss Per 100' of Hose</u>

Q = <u>gpm</u>

100

For 3½" hose = $\frac{Q \times (Q-1)}{2}$

For 4" hose = $\frac{Q \times (Q-1)}{4}$

For 5" hose = Q X (Q-1)
12

NOZZLE PRESSURE/NOZZLE REACTION (NP)

As water is discharged from a nozzle at a given pressure, a force pushes back on the firefighter(s) handling the hose line. This counterforce is known as nozzle reaction. The greater the nozzle pressure, the greater the nozzle reaction exerted on the firefighter(s). Lower nozzle pressures must be used with solid stream handlines due to the greater amount of nozzle reaction experienced with these nozzles. Handline nozzles are designed to be placed on mobile "quick attack" lines that can be easily maneuvered by firefighters. Master streams is a term used to describe any fire stream that is too large to be controlled without mechanical aid. Both master streams and handlines may be either fog or solid streams.

Standard nozzle pressures are as follows:

Smooth bore nozzle handlines = 50 psi.
Smooth bore nozzle master streams = 80 psi.
Variable flow fog nozzles on handlines = 100 psi.
Variable flow fog nozzles on master streams - 100 psi.
Penetrating nozzles = 100 psi.

For field use, the following discharge figures may be used:

	Nozzle Size	Nozzle Pressure	Approximate GPM Flow
Handlines:	1"	50 psi	200
	1_"	50 psi	250
	1¼"	50 psi	300
Master Streams:	1¼"	80 psi	400
	1_"	80 psi	500
	1½"	80 psi	600
	1_"	80 psi	700
	1¾"	80 psi	800
	2"	80 psi	1000

For estimating GPM for master streams with straight stream tips, the "rule of one-eighths" can be used. Convert the fraction of the tip size to one-eighth and add two to the numerator. This will be the GPM in hundreds of gallons.

Example: A 1¾" tip - ¾ = 6/8 - 6 + 2 = 8 or 800 GPM.
A 2" tip - 1 8/8 - 8 + 2 = 10 or 1000 GPM.

APPLIANCES (AP)

Fire hose appliances are attached to hoselines in order to combine or separate the original hoseline(s). These include wyes, siamese, and trimese. Appliance friction loss occurs when the flow is greater than 350 gpm.

Handline Appliances

1. The gated wye has an appliance friciton loss of 10 psi.

Master Stream Appliances

1. Siamese - 10 psi
2. Elkhart Monitor = 25 psi (in portable mode)

Truck mounted "deck" guns

1. Hush pumpers = 15 psi
2. Pierce pumpers = 25 psi
3. Seagraves pumpers = 30 psi
4. American LaFrance = 60 psi

Ladder Pipe - Standard Operation

1. LTI's (L271) = 70 psi of friction loss or 180 psi at the intake.
2. L273, E272, E278 (reserve telesquirt) has their own pump and should be given 20 psi for minimum intake pressure plus the friction loss in the hose.

Since newer ladder trucks have pressure relief valves that are set at 200 psi, the pump operator must be aware that anything over this pressure will be relieved. The flow meters on the ladder trucks will help to establish the correct flow.

ELEVATION PRESSURE (EL)

Elevation refers to the center line of the pump to the position of an object above or below *ground* level. Altitude is the position of an object above or below *sea* level. When a nozzle is above the pump, there is a pressure loss. When a nozzle is below the pump, there is a pressure gain. Both pressure loss and gain are referred to as elevation pressure.

Back Pressure - Pressure loss due to elevation. Going up in elevation adds to the pump discharge pressure.

Finding Pressure When Height is Known - Pressure = .434 X height in feet.

Finding Height When Pressure is Known - Height = 2.3 X pressure.

For Field Calculations - Back pressure = 1/2 pound per foot or five pounds per floor.

Going up in a multi-storied structure requires the subtraction of one floor from the fire floor before multiplying by 5.

Going down in elevation subtracts from the pump discharge pressure. Going down in floors, multiply 5 by number of floors below grade.

SPRINKLER SYSTEMS

Sprinkler systems are used in many modern structures for fire protection. The fire department sprinkler connection that supports these systems are generally found at street level, either on the building or remote from it. Depending on the size of the building and occupancy, there may be multiple fire department sprinkler connections located on different sides of the structure. All fire department sprinkler connections should be supported with fire department hose lines. Since pressures to sprinkler connections will not exceed 150 psi, 2½", 3½", or 4" supply hose can be used to supply the sprinkler connections. If using 2 ½" hose, connect to at least two connections.

Provide the following pressures at the fire department sprinkler connection:

100 psi with "nothing showing", but possible fire.

150 psi with "smoke showing", or "fire showing".

In order to determine the discharge in gpm from a sprinkler head, the following formula can be used:

GPM = ½ pressure + 15
or
GPM = 6 times √ pressure

FIREGROUND HYDRAULICS

<u>2½" Handline with Smooth Bore Nozzle</u> **<u>GPMFL</u> in 100' of 2-1/2" hose**

1" Tip	200	10#
1_" Tip	250	15#
1¼" Tip	300	20#

<u>Common Pump Discharge Pressures</u>

1 ½" Preconnect, 150' -- 130-180 psi*
1 ½" Preconnect, 200' -- 150-200psi*

Preconnect	GPM	Eng. Pressure @ 150 ft.	Eng. Pressure @ 200 ft.
1 ¾" Preconnect	95	113	118
1 ¾" Preconnect	125	121	128
1 ¾" Preconnect	150	132	142
1 ¾" Preconnect	175**	145**	160**
1 ¾" Preconnect	200	160	180

**** During active fire situations in an interior attack: 175 gpm nozzle flow is the absolute ideal minimum!!**

2" Preconnect, 200', with Automatic Nozzle -- 95 psi for 125 GPM (150' -- 90 psi) (one firefighter).
2" Preconnect, 200' with Automatic Nozzle -- 185 psi for 250 GPM (150' -- 160psi) (two firefighters).
2 ½" Preconnect -- 125 psi.
Deck Gun with Fog -- 115 psi to 160 psi depending on apparatus and quality of stream.
Deck Gun with Straight Stream -- 95 psi to 140 psi depending on apparatus and quality of stream.
Ladder Pipe -- adjust to good stream, and GPM from flow meter. Pressure relief valve on ladder trucks are set at 200 psi.

* Depending on circumstance and nozzleman preference.

Pressure by the book formula are so high that in use , the 1 ½" line is too stiff to maneuver. Some departments have modified the FL formula to allow for this problem, partly due to reduced friction loss in modern hose attack lines.

Water Availability From A Hydrant

1. Anytime multiple lines are used or a pressurized water supply is coming into the pump. the pressure relief device must be set. Failure to do so may cause a significant safety compromise for the firefighters on the hoselines.

2. The amount of water still available from a hydrant is determined by the difference between static and residual pressures.

A. 0 to 10% drop = 3 more like amounts
B. 11 to 15% drop = 2 more like amounts
C. 16 to 25% = some more water

3. Fireground formula (first digit method)

   A. Find the difference between the static and residual pressures.
   B. Multiply the first digit of the static pressure by 1.
   C. Compare the answer to the difference between pressures
      1. If the answer is equal to or greater than the difference, the hydrant will supply 3 more like amounts.
      2. If the answer is less than the difference, multiply by 2 and compare. If multiplying by two makes the answer equal to or greater than the difference, the hydrant will supply 2 more like amounts.
      3. Having to multiply by 3 to meet parameters in #1 gives you 1 more like amount.
      4. Having to multiply by 4 to meet parameters in #1 gives you some more water only.

Example 1

Static =	90	First digit of static pressure (9) X 1 = 9
Residual = 84		
Difference of	06	9 is equal to or greater than 6 so the hydrant will supply 3 more amounts

Example 2

Static =	90	First digit of static pressure (9) X 1 = 9
Residual = 76		
Difference of	14	9 is less than 14 so multiply 9 by 2 = 18 and compare. 18 is equal to or greater than 14 so the hydrant will supply 2 more amounts.

Class B Foam (AFFF-ATC)

1. When pumping foam, remember, you are pumping the eductor.
   A. Inlet rating of 200 psi.
   B. Flow rating of 95 psi.

2. Regardless of the location of the eductor, you must pump 200 psi. to the inlet of the eductor.

3. The nozzle must match the GPM rating of the eductor
   A. Set the nozzle at 95 gpm.
   B. The nozzle must be completely open.
   C. All kinks must be removed from the line

4. Back Pressure

   A. BP = NP + FL + EL
   B. Maximum BP is 70% of the inlet pressure to the eductor (200 psi)
      70% of 200 psi is 140 psi for our eductors.

5. Foam Application
   A. Foam applications will be pumped at 200 psi to the eductor.
   B. 350" maximum. 95 gpm nozzle setting

6. <u>EDUCTOR SETTING</u> <u>FOAM CONCENTRATE CONSUMPTION</u>

6%		6 GPM
3%	3 GPM	
1%	1 GPM	
½%	½ GPM	